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DNA 4008T-KAK-SAN

[redacted]

COMMUNICATION FACILITY EMP ASSESSMENT [redacted]

[redacted]

Boeing Aerospace Company
P.O. Box 3999
Seattle, Washington 98124

30 March 1979

Sanitized

Topical Report for Period 1 September 1975–30 March 1979

CONTRACT No. DNA 001-76-C-0076

[redacted]

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[redacted]

Prepared for
Director
DEFENSE NUCLEAR AGENCY
Washington, D. C. 20305

[redacted]

Encl. 5

[redacted]

[redacted]

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: DNA 4008T-KAK SAN	2. GOVT ACCESSION NO. [redacted]
	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): COMMUNICATION FACILITY EMP ASSESSMENT [redacted]	5. TYPE OF REPORT & PERIOD COVERED: Topical Report for Period 1 Sep 75—30 Mar 79
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): SV&H Engineering Staff	8. CONTRACT OR GRANT NUMBER(s): DNA 001-76-C-0076
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Boeing Aerospace Company, P.O. Box 3999, Seattle, Washington 98124	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Subtask G37KAXEX475-17
11. CONTROLLING OFFICE NAME AND ADDRESS: Director, Defense Nuclear Agency, Washington, D.C. 20305	12. REPORT DATE: 30 March 1979 [redacted]
	13. NUMBER OF PAGES: 58
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS (of this report): [redacted]
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE: [redacted]

16. DISTRIBUTION STATEMENT (of this Report)

[redacted]

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This work sponsored by the Defense Nuclear Agency under RDT&E RMSS Code B363078462 G37KAXEX47517 H2590D.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Electromagnetic Pulse (EMP)	Upset Thresholds
[redacted]	Damage Thresholds
Hardening Concept	Critical Equipment
Safety Margin	Hardening Design Package
Survival Confidence	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents an assessment of the Technical Control Facility (TCF) and the Microwave Terminal (MWT), [redacted] to EMP based upon electromagnetic analysis, functional analysis, and operational performance requirements.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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[redacted] SUMMARY [redacted]

[redacted] A scenario variant EMP assessment has been performed for the Technical Control Facility and Microwave Terminal elements at the communications facility located [redacted] The EMP assessment considered the effects induced by EMP environments generated by high-altitude nuclear detonations. The scenario variant technique identifies the critical electrical/electronic equipment predicted to be impaired by the largest signals induced within the facility by any high-altitude nuclear EMP environment.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted] TABLE OF CONTENTS

[redacted]

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[redacted] LIST OF ILLUSTRATIONS

[redacted] LIST OF TABLES

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1.0 [redacted] INTRODUCTION

1.1 BACKGROUND

The Commander-in-Chief [redacted] and the Defense Nuclear Agency (DNA) have undertaken an Assessment of [redacted] Communications for Hardening to Electromagnetic Pulse [redacted] to assess the vulnerability of the [redacted] Command's [redacted] Control, Communications and Computer (C^4) Networks to electromagnetic pulses from high altitude nuclear bursts and to provide recommendations for hardening as may be required. [redacted] Networks are used to link [redacted] with the National Command Authority (NCA), subordinate and component headquarters, and the [redacted] forces.

The Boeing Aerospace Company has developed and validated analytical techniques to predict the functional responses of a communications facility to the environment produced by an electromagnetic pulse (EMP) scenario. The analytical capability has been applied to selected elements of the [redacted] C^4 Networks to develop response predictions in terms of upset and damage of facility equipment and functional impairments of facility communications capabilities. Keymor B.

This report concerns two elements of the [redacted] communications facility, [redacted]. The elements are the Technical Control Facility (TCF) and the Microwave Terminal (MWT). The TCF provides signal conditioning and routing functions for the MWT, [redacted] The MWT provides the microwave communication links between [redacted] and [redacted]

An on-site survey was conducted in February 1976 to determine the EMP features and element descriptions for use in the facility analysis. Equipment configuration and operational data were used to develop the electromagnetic coupling and functional analyses of specified critical equipment. Computer models were developed to calculate the waveforms induced by EMP at significant terminals

[redacted]

on critical equipment. The peak amplitudes of the waveforms were compared to calculated equipment damage and upset thresholds to predict the probability of the equipment surviving an EMP event.

1.2 SCOPE

This report presents the element descriptions, element and facility functional analysis, and element response assessments to the postulated, worst-case nuclear EMP environment for the Technical Control Facility (TCF) and Microwave Terminal (MWT) of the communications facility [redacted]

[redacted]

2.0 [redacted] PREDICTED EMP VULNERABILITY AND EFFECTS [redacted]

[redacted]

[redacted] Specific EMP assessment predictions for the TCF and MWT critical equipment are in Appendix A.

[redacted]

[redacted]

3.0 [redacted] FACILITY HARDENING [redacted]

[redacted]

[redacted]

[redacted]

APPENDIX A

[redacted] EMP ASSESSMENT PREDICTIONS [redacted]

A.1 [redacted] GENERAL

A scenario variant (SV) assessment technique was used for assessing the effects of EMP on the Technical Control Facility and Microwave Terminal at the communications facility [redacted] Using the SV technique provides for making element assessments, and developing hardness concept design packages to provide a desired survival confidence level, for the most severe, high-altitude, nuclear burst EMP environment.

The EMP assessment predictions were calculated by using the scenario variant assessment technique described in Appendix B.

A.2 [redacted] SCENARIO VARIANT ASSESSMENT DATA [redacted]

[redacted] The scenario variant assessment predictions for the critical equipment items are provided in Tables A.2-1 and A.2-2. For each critical equipment item, the largest predicted peak voltage and associated pulse frequency are provided, as are the upset and damage thresholds. Tables A.2-1 and A.2-2 also provide the safety margin and survival confidence values for each critical equipment item. The safety margin and survival confidence predictions each depend upon the predicted peak voltage. Since the SV assessment technique defines the maximum potential EMP-induced peak voltage at the critical equipment interface, the predicted safety margin and survival confidence values are the minimum levels expected for any high-altitude nuclear EMP environment condition.

[redacted] The predicted safety margin is the ratio, in dB, between the threshold voltage and the predicted peak voltage. The survival confidence values were determined using the predicted safety margins and the data quality distribution which characterizes the statistical uncertainties in safety margin predictions. For the calculations used for this assessment, the data quality distribution was chosen as normally distributed with a zero mean and a standard deviation of 8 dB. This distribution was used since it is the data quality indicated from previous test experience.

 Pages 10 through 19 Were deleted.

[redacted]

[redacted]

[redacted]

[redacted]

APPENDIX B

[redacted] EMP VULNERABILITY ASSESSMENT TECHNIQUE

B.1 GENERAL

The assessment technique is a step-by-step procedure to gather and process the necessary information to arrive at an element assessment. The technique consists of nine operations:

1) Perform a site survey
2) Develop a functional description of the equipments and the element
3) Define the equipment critical to element operations
4) Provide a floor plan showing all equipment locations
5) Produce an equipment list for inherently survivable equipment
6) Calculate threshold values for each critical equipment
7) Develop element-level computer models
8) Calculate critical equipment responses to scenario variant nuclear EMP environment
9) Propose hardening techniques and modifications for predicted vulnerable equipment

Each of these nine operations is amplified in greater detail in the following paragraphs.

B.1.1 Site Survey

The test team reviewed all on-site documentation relating to the physical configuration of building and local, surrounding structures.

A drawing of the facility area was made to show the relationship between the structure housing, the critical equipment and the external collectors of EMP energy. Typical external collectors plotted are

[redacted]

1) Power poles
2) Transformers and power switches
3) Ground or counterpoint systems
4) Antennas
5) Towers
6) Weatherheads and power drops
7) Communications cable routing
8) Incoming ac transmission links

The plot plans for the TCF and MWT elements of the [redacted] facility are in Appendix C.

B.1.2 Facility Functional Description

The on-site documentation also provided a functional description of the facility. The functional description was used to gain an understanding of the operating characteristics of the different systems in the facility and the equipments comprising the systems. The knowledge of how the systems and equipments work and interrelate with each other was used to evaluate the responses of the systems and equipments to the EMP environment. The responses have been translated into operational capabilities lost or remaining during and after an EMP event.

B.1.3 Critical Equipment Definition

The on-site documentation was reviewed to identify those equipments which support critical [redacted] C^4 networks, and the equipments so identified were reviewed by site personnel. A critical piece of equipment was defined as that equipment considered essential for operating a critical subsystem. A critical subsystem performs a primary function, and the loss of the function results in a reduced system capability.

[redacted]

[redacted]

B.1.4 Critical Equipment Layout

An equipment layout plan was developed showing the location and orientation of each piece of critical equipment within the building structures. Major internal coupling paths, such as cable trays, ducts and conduit, were included. Appendix C shows the critical equipment layouts for the TCF and MWT elements considered in this report.

B.1.5 Survivable Equipment List

From the list of critical equipment, those equipments which prior assessment experience indicates has a safety margin of [redacted] or greater were eliminated from further analytical consideration. Such items were classified as hard and survivable at the [redacted] percent confidence level. The remaining critical equipment items received analysis emphasis.

B.1.6 Critical Equipment Thresholds

Damage thresholds were developed for the remaining items on the critical equipment list. The voltage or current thresholds beyond which equipment damage occurs were calculated using the equipment characteristics defined in the on-site documentation, and previously developed analysis and mathematical modeling techniques. The predicted thresholds were calculated on the basis that the specific equipment is expected to be damaged if the predicted threshold levels are attained or exceeded. The damage thresholds for the TCF and MWT critical equipment are listed in Appendix A.

B.1.7 Computer Model Development

Element-level computer models were developed for the critical equipment, the facility functional systems, facility coupling paths and penetration points, and the external electromagnetic energy collectors using the site survey and equipment

[redacted]

documentation data. The models were used to represent the TCF and MWT elements; external environment computer software programs were used to calculate the response waveforms induced by the EMP environment at the critical equipment interfaces in each element.

B.1.8 Scenario Variant Assessment

The scenario variant (S/V) assessment technique uses a software program that defines seventeen nuclear bursts in the hemisphere above a ground facility and mathematically propagates the EMP from each burst against the models representing the critical equipment, functional systems, coupling paths, penetration points, and the external electromagnetic collectors for an element. [redacted]

The predicted damage responses calculated using the S/V technique for each critical equipment in the TCF and MWT elements are tabulated in Appendix A.

B.1.9 Hardening Techniques and Design Packages

Hardening techniques were developed for each critical equipment predicted to be vulnerable to the most severe, high-altitude, nuclear EMP environment. Tables listing equipment requiring electromagnetic hardening, and recommended hardening techniques are in Section 3.0. Hardening design packages were developed for each vulnerable critical equipment from the hardening techniques, and are also contained in Section 3.0.

[redacted]

APPENDIX C

[redacted] PLANT DESCRIPTIONS

C.1 PHYSICAL DESCRIPTION

C.1.1 [redacted] Communications Facility

The [redacted] communications facility is located on the [redacted] The Technical Control Facility (TCF) and Microwave Terminal (MWT) are located i[redacted] Figure C.1-1 is a pictorial view of Communication[redacted]and the MWT microwave tower.

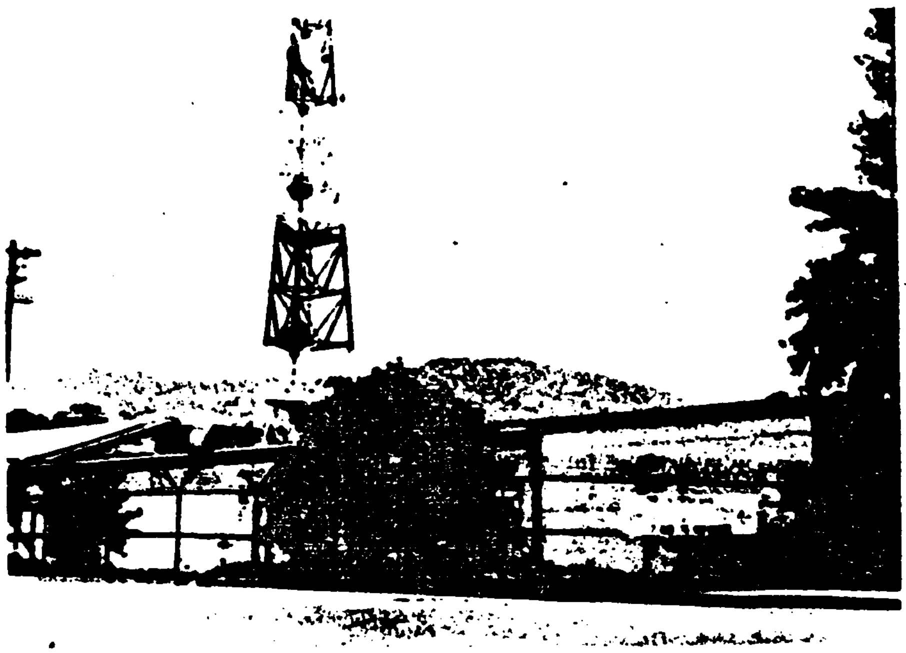


Figure C.1-1. Pictorial view of [redacted] communications facility, [redacted]

[redacted]

[redacted]

Figure C.1-2 shows a plot plan of the [redacted] communications facility. The TCF and MWT are located in [redacted] which is a concrete block structure with steel reinforcing. The plan also shows facilities that are related to the TCF and MWT. [redacted]

Commercial ac power [redacted] is supplied to the TCF and MWT by 11.4 kV overhead power lines and a buried 5.0 kV power cable. Emergency ac power is provided to the facility by four 300 kW diesel generators. The generators are located in the power generator [redacted] shown in Figure C.1-2.

Uninterruptible power supply (UPS) system and a 125 kVA static inverter are used to provide no-break power for the [redacted] equipment, communication security equipment and the [redacted] terminal equipment. The UPS equipment located in [redacted] provides backup power should both commercial and site emergency ac power fail.

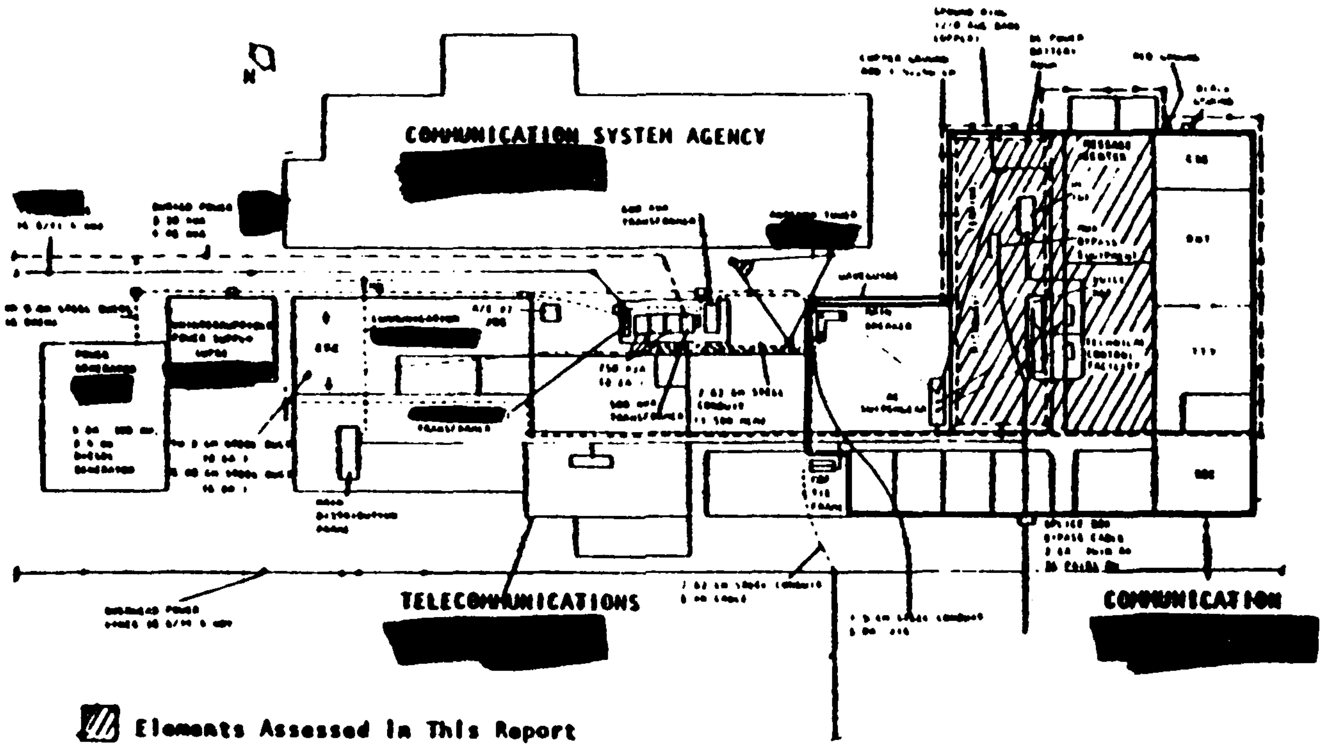
Grounding for the facility is provided by a series of grounds rods buried around the exterior of the building. These ground rods are interconnected and tied at several points to the interior ground network by bare 2/0 copper cables. The antenna tower and all waveguides are grounded to the exterior ground counterpoise system.

C.1.2 Technical Control Facility

The equipment layout for the TCF is shown in Figure C.1-3. The TCF equipment is grounded via overhead ground cables that are tied to ground buses located in the microwave room. The ground straps are tied to the ground bus which is routed around the inner wall of the microwave room. The microwave room ground bus is tied to the facility's exterior grounding system as shown in Figure C.1-2. Signal and control cables are routed via open overhead cable trays and floor trenches. The trays are grounded to the equipment frames.

[redacted]

[redacted]



Elements Assessed In This Report

Figure C.1-2. Communications facility plot plan, [redacted]

[redacted]

[redacted]

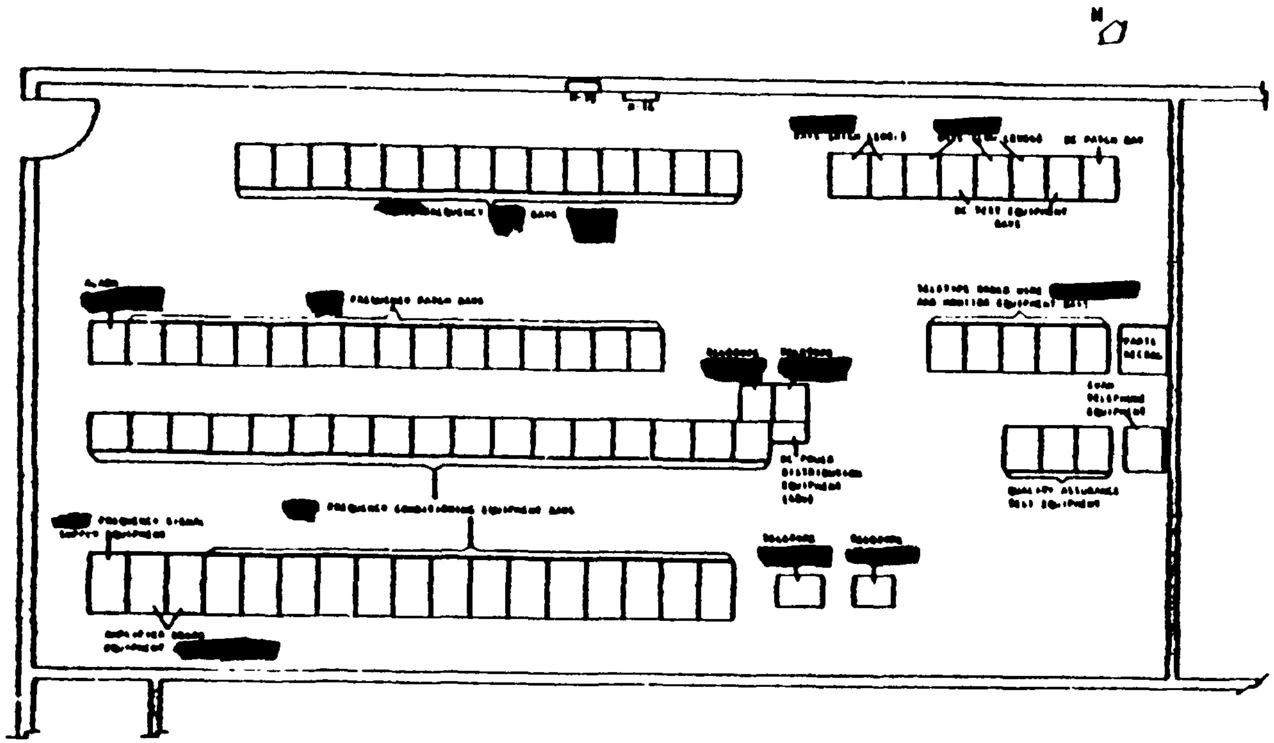


Figure C.1-3. TCF equipment layout, [redacted]

[redacted]

Unfiltered ac power is routed from the main distribution panel to the TCF via cable trays which are 2.1 meters above the floor. DC power is supplied to the TCF by two 500 MCM (thousand circular mil) cables from the microwave terminal and is also provided by individual equipment power supplies.

C.1.3 Microwave Terminal

The MWT equipment layout is shown in Figure C.1-4. Th[redacted] microwave system is used to provide a link between [redacted] and the [redacted] facility [redacted] The [redacted] microwave systems terminal uses the [redacted] and [redacted] multiplex systems.

The [redacted] microwave equipment is operated on 120 Vac commercial power. AC power is distributed to the equipment by overhead steel conduits.

DC power is provided to the [redacted] microwave equipment by three 400 ampere/48 Vdc power supplies/rectifiers. Emergency dc power is provided by a 48 V battery bank. DC power cables are routed to the appropriate microwave equipment on cable racks 3.0 meters above the floor.

Communications and control cables are routed within the MWT using open overhead cable racks 3.0 meters above the floor. The cables consist of shielded and unshielded twisted pairs.

The MWT equipment is grounded via overhead ground cables tied to a ground bus laid along the inner wall of the MWT room. Equipment racks, cable trays, and dc returns are also grounded to the overhead ground cables.

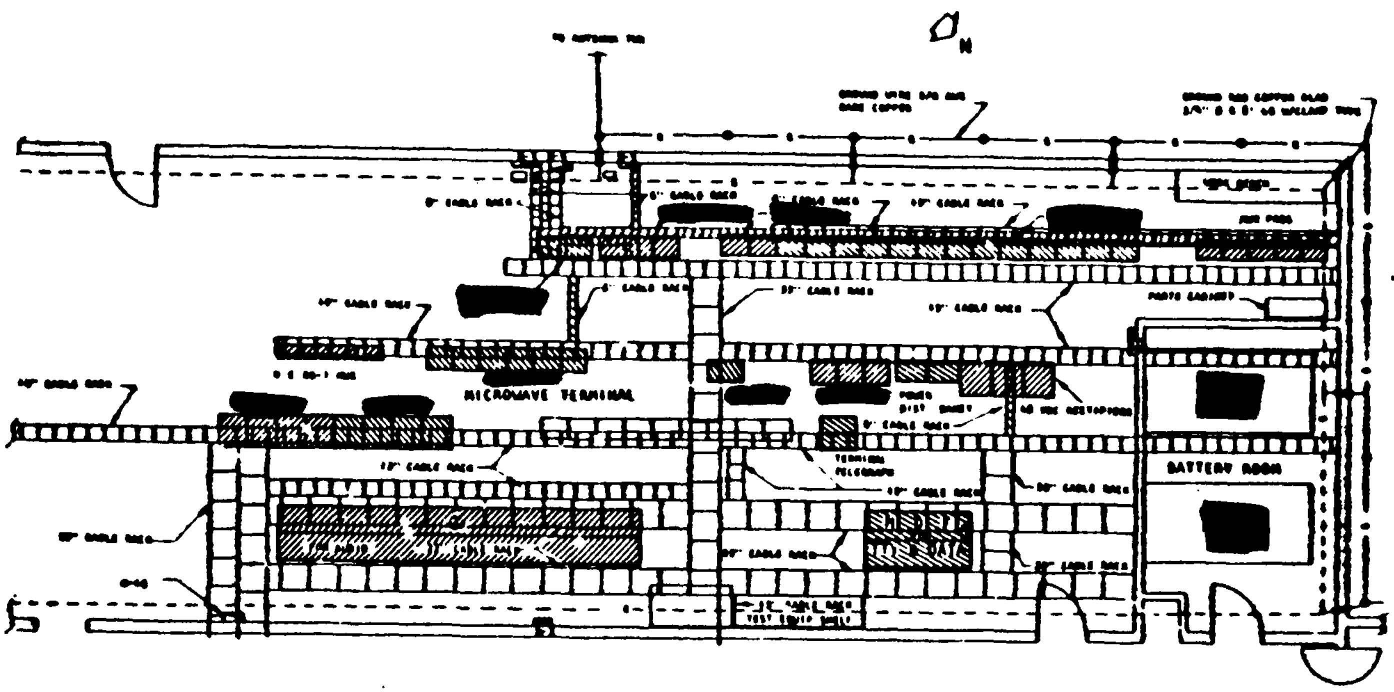


Figure C.1-4. MW/T equipment layout, [redacted]

[redacted]

APPENDIX D

[redacted] FUNCTIONAL DESCRIPTIONS

D.1 GENERAL

Figure D.1-1 shows the connectivity between elements within the [redacted] communications facility and the connectivity between [redacted] and [redacted] facilities with the shaded areas showing the elements covered by this report. The TCF acts as the central patch, test, and routing control for all incoming and outgoing messages.

D.2 ELEMENT FUNCTIONAL DESCRIPTIONS

D.2.1 Technical Control Facility

The TCF provides the signal conditioning and signal routing functions between the [redacted] and [redacted] subscribers. Message traffic entering and leaving the TCF is single channel voice frequency and low level teletype (TTY) data which is transmitted and received over twisted pairs. The low level teletype signals are not conditioned by equipment in the TCF. Figure D.2-1 shows the signal paths and the associated conditioning equipment.

The [redacted] circuit conditioning equipment can operate from 115 Vac power or from dc power supplies which are powered from the 115 Vac line. Most of the conditioning equipment for the other voice and data circuits are dc powered by 48 Vdc battery banks which are constantly charged by three [redacted] rectifiers. The battery banks provide a minimum of 4 hours of reserve power. The equalizers and audio limiters use 115 Vac power. The ac power needed for the signal conditioning equipment is supplied from diesel powered generators.

Results of the functional analysis indicate that the equipment listed in Table D.2-1 are critical for operation of the [redacted] TCF. Included for each

[redacted]

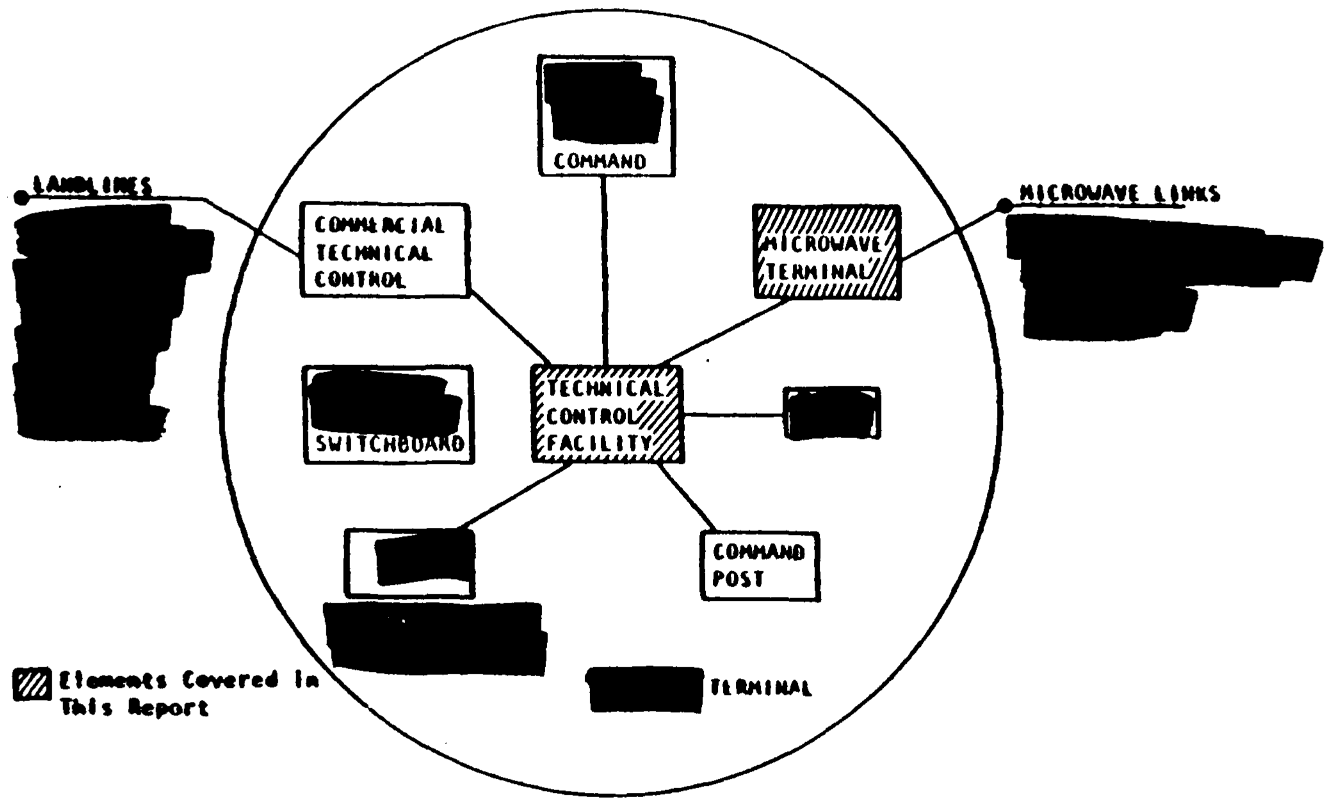


Figure B.1-1. Connectivity [redacted]

[redacted]

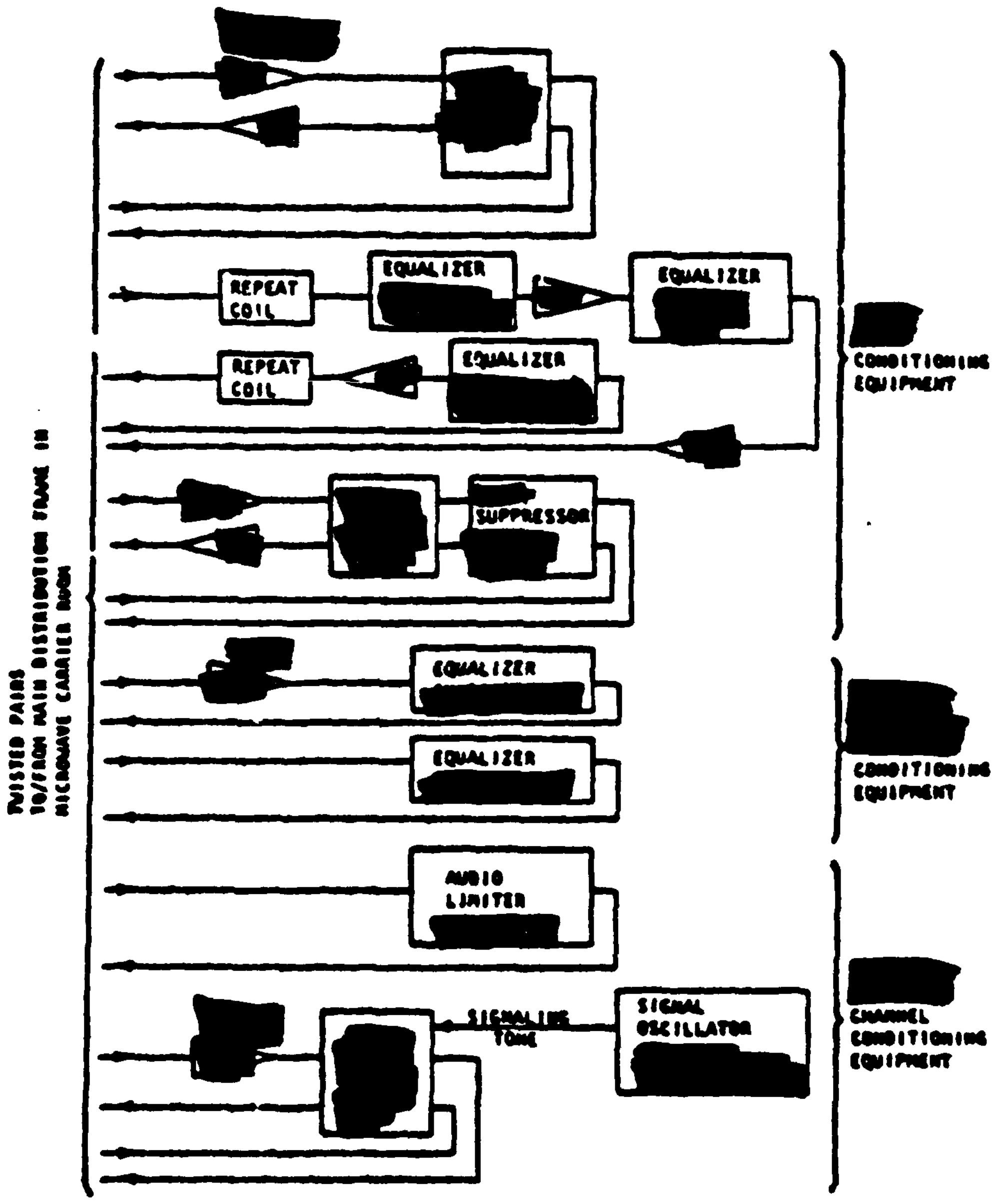


Figure B.2-1. Signal paths and associated conditioning equipment, [redacted]

[redacted]

[redacted]

Table D.2-1. TCF functional response matrix for critical equipment.

Critical Equipment	Functional Response
Power Supply [redacted]	Failure will result in the loss of primary power and the eventual (4 hour) loss of battery power. Restoration is by replacement. [redacted] circuit will not be affected by loss of supplies.
Equalizers [redacted]	Failure will result in the loss of data [redacted] and some [redacted] circuits. Restoration is by patching to other units (some spares) or by repair.
Line Amplifiers [redacted]	Failure will result in the loss of some data circuits. Restoration is by patching to other line amplifiers or by repair.
Signaling Oscillator/Amplifier [redacted]	Failure will result in the loss of signaling on voice calls. Not all units may fail simultaneously. Restoration is by repair.
Single Frequency Signaling Unit [redacted]	Failure will result in the loss of signaling on voice calls. Not all units may fail simultaneously. Restoration is by replacement (some spares) or by repair.
Line Amplifier [redacted]	Failure will result in the loss of voice calls. Not all units may fail simultaneously. Restoration is by replacement (some spares) or by repair.
Audio Limiter [redacted]	Failure will result in the loss of some VF channels. Restoration is by replacement. Numerous spares are available.

[redacted]

Table B.2-1. TCF functional response matrix for critical equipment (continued).

Critical Equipment	Functional Response
Single Frequency Signaling Unit [redacted]	Failure will result in the loss of the [redacted] circuit between [redacted]. Not all units may fail simultaneously. One spare is available for restoration. [redacted] circuit could be patched through, using [redacted] dedicated equipment, within 1 hour.
Power Supply [redacted]	Failure will result in the loss of power to [redacted] dedicated single frequency signaling units, amplifiers, and echo suppressors. Restoration by repair or by patching in station battery 48 Vdc.
Equalizer [redacted]	Failure will result in the loss of the [redacted] circuit from [redacted] Restoration is by repair or by patching alternate path from [redacted] using [redacted] dedicated equipment.
Line Amplifier [redacted]	Failure will result in the loss of all [redacted] circuits. Not all units may fail simultaneously. Restoration by repair or by patching through [redacted] dedicated amplifiers requiring 1 hour.
Repeat Coils [redacted]	Failure will result in the loss of the [redacted] circuit from [redacted]. Restoration by replacement. Some spares are available.
[redacted] Suppressor [redacted]	Failure will result in the loss of the [redacted] circuit from [redacted]. Restoration by patching around unit with some loss of intelligibility.

[redacted]

Table 0.2-1. TCF functional response matrix for critical equipment (continued).

Critical Equipment	Functional Response
Equalizer [redacted]	Failure will result in the loss of the [redacted] circuit from [redacted]. Restoration by repair or by patching alternate route through [redacted] using non [redacted] dedicated equipment.

[redacted]

[redacted]

critical equipment is the functional impact to TCF operations which will occur if the equipment is impaired.

D.2.2 Microwave Terminal

The MWT consists of three microwave systems and four multiplexer groups. The microwave links are the primary sources of communication to [redacted] A block diagram indicating the functional flow of communications through the MWT and the associated equipment is shown in Figure D.2-2.

The microwave link to [redacted] utilizes an [redacted] system operating in the dual frequency and space diversity modes. The link to [redacted] utilize an [redacted] system operating in the dual frequency diversity mode. The link to [redacted] utilizes a [redacted] system operating on a single frequency and having a spare transmitter/receiver in a hot standby condition.

There is an alternate (bypass) system to transmit data via the [redacted] MW system in event the [redacted] is down. A [redacted] multiplexer is provided for the bypass. The TCF can patch data lines, that normally go to the [redacted] multiplexers, to the [redacted] multiplexer. The multiplexer connects to the [redacted] system via landlines for communications with [redacted] The alternate system has sixty channels assigned to the [redacted] and sixty channels assigned to the U.S. Forces. Link capacities and operating frequencies are shown in Table D.2-2.

Power for the [redacted] link is 120 Vac commercial power backed up by two site generators and an emergency generator. Power for the [redacted] and [redacted] links is three 400-ampere/48 Vdc power supplies. In addition, the power supplies constantly charge battery banks to provide an eight-hour minimum backup power reserve.

[redacted]

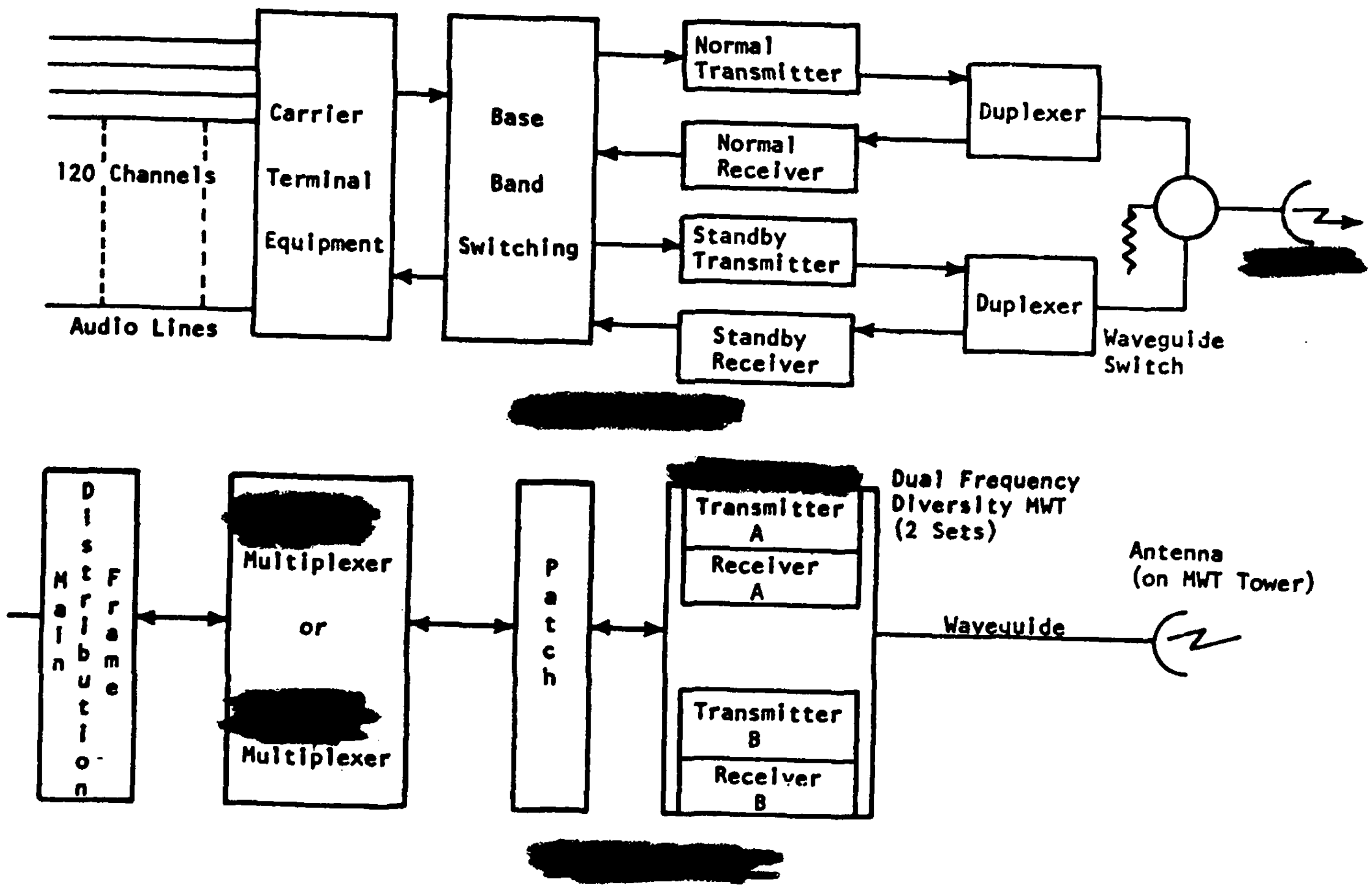


Figure D.2-2. Communications functional flow and associated equipment, [redacted]

[redacted]

Table D.2-2. [redacted] capacity and operating frequencies.

[redacted] To:	Transmit Frequency (MHz)	Receive Frequency (MHz)	Channel Capacity	Active Channels
[redacted]	[redacted]	[redacted]	600	468
[redacted]	[redacted]	[redacted]	444	444
[redacted]	[redacted]	[redacted]	120	120

Results of the functional analysis indicate that the equipment listed in Table D.2-3 are critical for operation of the MWT. Included for each critical equipment is the functional impact to microwave terminal operations if the equipment is impaired.

[redacted]

[redacted]

Table D.2-3. MWT functional response matrix for critical equipment.

Critical Equipment	Functional Response
Microwave Transceiver [redacted]	Failure will result in the loss of transmit and/or receive capability to/from [redacted] Restoral is by repair or replacement.
Multiplexer [redacted]	
Microwave Transceiver [redacted]	Failure will result in the loss of transmit and/or receive capability to/from [redacted] Restoral is by repair or replacement.
Multiplexer [redacted]	
Microwave Transceiver [redacted]	Failure will result in the loss of transmit and/or receive capability to/from [redacted] Restoral is by repair, replacement, or by switching [redacted] the hot standby transceiver.
Multiplexer [redacted]	
Multiplexer [redacted]	Failure will result in the loss of transmit and/or receive capability of the [redacted] bypass system to/from [redacted] (sixty channels assigned to [redacted] and sixty channels assigned to U.S. Forces). Restoral is by repair, replacement, or by using the primary communication route.
Power Supply, 48 Vdc [redacted]	Failure will result in the loss of transceive capability to/from [redacted] after depleting the eight-hour minimum battery backup reserve. Restoral is by repair or replacement.

[redacted]

[redacted]

APPENDIX E

[redacted] ELECTROMAGNETIC ANALYSIS

E.1 GENERAL

The construction of the building housing the [redacted] is concrete block with steel reinforcing. The building shielding measured at the site ranged from [redacted] Direct coupling of EMP to internal conductors is treated in the model by attenuating incident EMP fields by [redacted]

E.2 TCF EM PENETRATIONS AND COUPLING PATHS

The major electromagnetic penetrations of the [redacted] as shown in Figure E.2-1, are

1) The ac power system
2) Field drive on cable trays and distribution frame
3) Field drive on cables to the joint overseas switchboard

Considering the major EM penetrations to the TCF critical equipment, the coupling paths joining these penetrations to the critical equipment were selected for the EM analysis.

E.3 MWT EM PENETRATIONS AND COUPLING PATHS

The major penetrations of the [redacted], as shown in Figure E.3-1, a

1) Microwave tower and waveguides
2) TCF cabling
3) Ground system
4) Commercial ac power
5) [redacted] Switchboard [redacted] cables
6) [redacted] bypass cable

[redacted]

[redacted]

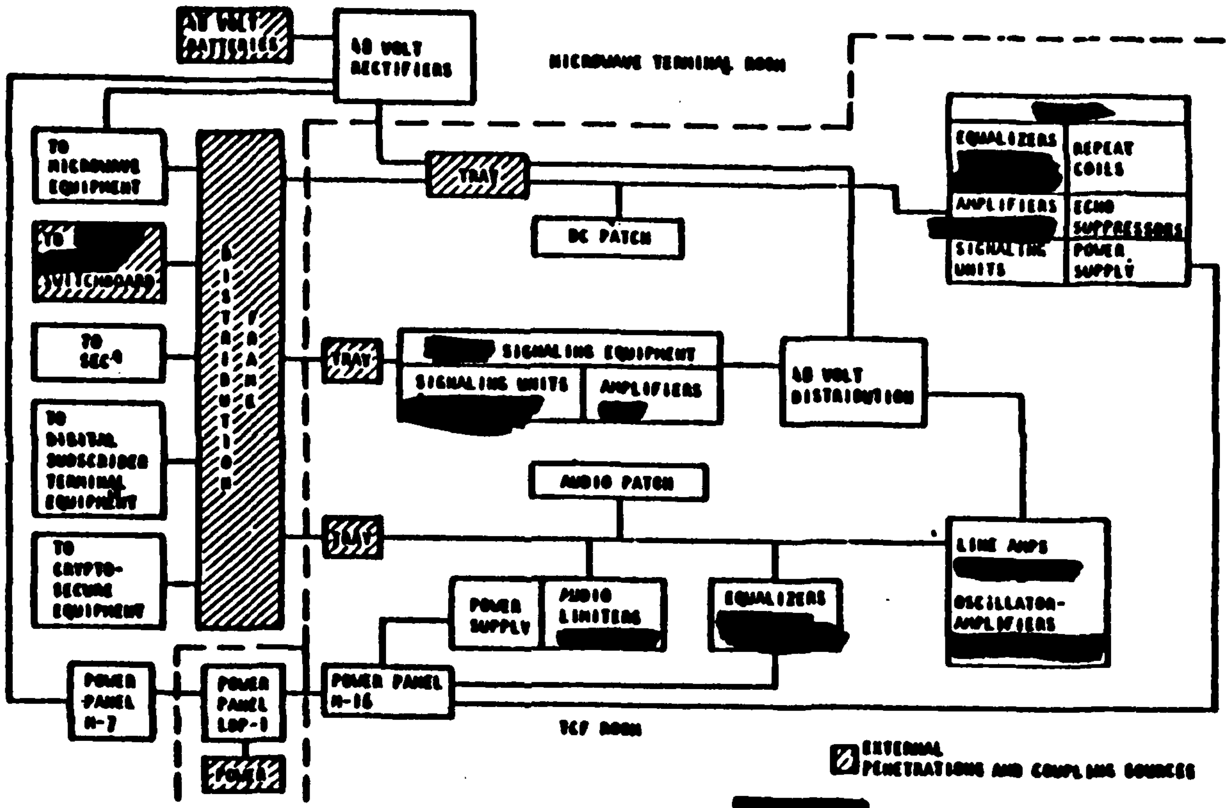


Figure E.2-1. Major penetrations and coupling paths, [redacted]

[redacted]

[redacted]

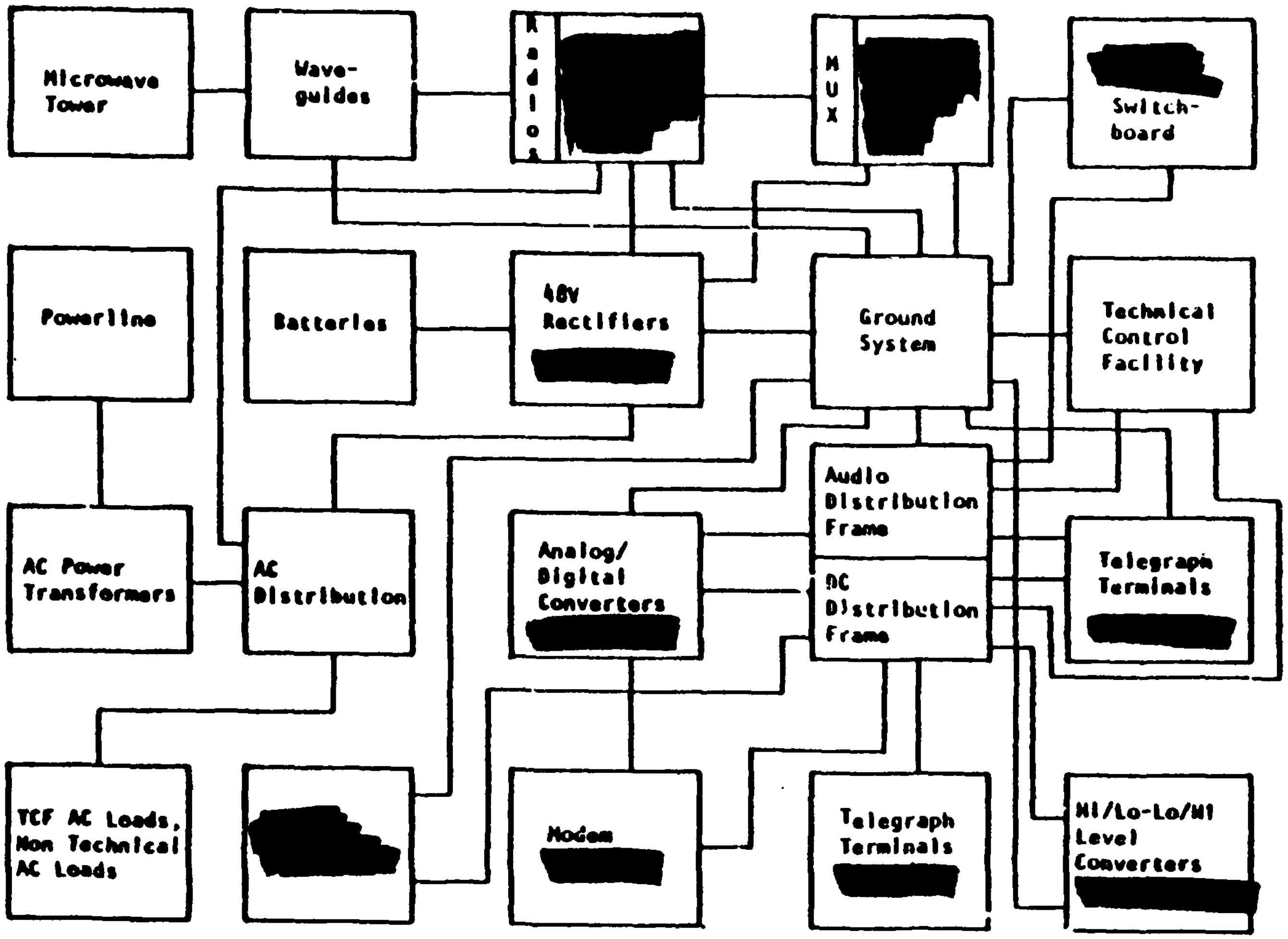


Figure E.3-1. Major penetration and coupling path diagram, [redacted]

[redacted]

[redacted]

This, together with the critical interface list, led to the following list of critical coupling paths:

1) AC power conduit system
2) Tray - MUX cable coupling
3) DC distribution system
4) Audio cables from TCF to distribution frame (df)
5) Low-level signal cables from TCF to df
6) [redacted] and [redacted] cable coupling to df

These were the penetrations and coupling paths that received major emphasis in the EM modeling effort.

Additional features concerning this nodal element EM model are

1) The ac power coupling to critical circuits was considered significant because the ac power system is normally tied directly to commercial power.

2) The signal cable drives are weak because all cabling (grounding, dc distribution, ac distribution and communication) is at the same overhead level, i.e., loop pickup is small.

E.4 EM MODEL DEVELOPMENT

The locations and shielding of the penetrations, the layout of the coupling paths, and the locations and types of critical circuits determine the configuration of the final electromagnetic model coded into a computer to calculate the critical equipment responses to the most severe, high-altitude, nuclear EMP environment.

[redacted]

[redacted]

APPENDIX F

[redacted] BONDING* AND ASSEMBLY INSTRUCTIONS

F.1 BONDING

Bonding refers to the process by which a low impedance path for the flow of an electric current is established between two metallic objects.

F.1.1 Surface Platings or Treatments

Surface treatments, to include platings provided for added wearability or corrosion protection, shall offer high conductivity. Plating materials shall be electrochemically compatible with the base metals. Unless suitably protected from the atmosphere, silver and other easily tarnished metals shall not be used to plate the bond surfaces.

F.1.2 Bond Protection

All bonds shall be suitably protected against weather, corrosive atmospheres, vibrations and mechanical damage. Under dry conditions a corrosion preventive or sealant shall be applied within 24 hours of assembly of the bond materials. Under highly humid conditions, sealing of the bond shall be accomplished within one hour of joining.

F.1.3 Corrosion Protection

Each bonded joint shall be protected against corrosion by assuring that the metals to be bonded are galvanically compatible in accordance with DCA Notice 310-70-1**. Bonds shall be painted with a moisture proof paint conforming to the requirements of FED-STD T-TP-1757 or shall be sealed with a silicone or petroleum-based sealant to prevent moisture from reaching the bond area. Bonds

* taken from MIL-STD-188-124
**DCA Notice 310-70-1 will be replaced by MIL-HDBK-419 upon release of 419.

[redacted]

[redacted]

which are located in areas not reasonably accessible for maintenance shall be sealed with permanent waterproof compounds.

F.1.4 Vibration

Bonds shall be protected from vibration-induced deterioration by assuring that bolts and screws are torqued in accordance with DCA Notice 310-70-1.

F.1.5 Bonding Straps

Bonding straps installed across shock mounts or other suspension or support devices shall not impede the performance of the mounting device. They shall be capable of withstanding the anticipated motion and vibrational requirements without suffering metal fatigue or other means of failure. Extra care shall be utilized in the attachment of the ends of bonding straps to prevent arcing or other means of electrical noise generation with movement of the strap.

F.1.6 Bond Resistance

All bonds for ground conductors whose primary function is to provide a path for power, control, or signal currents shall have a maximum dc resistance of one milliohm. The resistance across joints or seams in metallic members required to provide electromagnetic shielding shall be one milliohm or less.

F.1.7 Clamps

Bonding clamps shall conform to AN 735 or AN 742.

F.1.8 Nuts, Bolts, and Washers

Nuts and bolts shall be capable of meeting the torque requirements of DCA Notice 310-70-1. Flat washers shall not be surface treated: they shall be protected as specified in paragraph F.1.18 and F.1.19 for corrosion control purposes. Star washers smaller than 1.2 cm (1/2 inch) shall not be used.

[redacted]

F.1.9 Direct Bonds

Wherever possible, bonding of metallic or other conductive members shall be accomplished by direct contact of the mating surface with the electrical path achieved by a welded, brazed, soldered, or high-compression bolted connection.

F.1.10 Welding

Permanent conditions between ferrous materials shall be welded whenever possible.

F.1.11 Brazing and Silver Soldering

Brazing or silver soldering is acceptable for the permanent bonding of copper and copper alloy materials.

F.1.12 Bonding of Copper to Steel

Either brazing or exothermic welding shall be used for the permanent bonding of copper conductors to steel or other ferrous structural members.

F.1.13 Soft Soldering

Soft soldering shall not be used for bonding purposes.

F.1.14 Sweat Soldering

Sweat soldering shall be used for electrical bonding only when other fasteners such as bolts or rivets are concurrently used to provide mechanical strength.

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F.1.15 Bolting

All bonds utilizing bolts and other threaded fasteners shall conform to the minimum torque requirements given in DCA Notice 310-70-1. Inspection shall be conducted periodically. Before joining, all faying surfaces shall be prepared per paragraph F.1.18. Particular care shall be taken to provide adequate corrosion protection to all electrical bonds made with bolts and other threaded fasteners.

F.1.16 C-Clamps and Spring Clamps

C-clamps and spring clamps shall not be used for permanent or semi-permanent bonding.

F.1.17 Indirect Bonds

Where the direct joining of structural elements, equipments, and electrical paths is impossible or impractical to achieve, bonding straps or jumpers shall be used.

F.1.18 Surface Preparation

All mating surfaces which comprise the bond shall be thoroughly cleaned before joining to remove dust, grease, oil, moisture, nonconductive protective finishes, and corrosion products.

1) <u>Area to be Cleaned</u>. All bonding surfaces shall be cleaned over an area that extends at least .5 cm (1/4 in.) beyond all sides of the bonded area on the larger member.
2) <u>Paint Removal</u>. Paints, primers, and other organic finishes shall be removed from the metal.
3) <u>Inorganic Film Removal</u>. Rust, oxides, and nonconductive surface finishes such as anodize shall be removed.

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4) Final Cleaning. After initial cleaning with chemical paint removers or mechanical abrasives, the bare metal shall be wiped or brushed with dry cleaning solvent meeting the requirements of Federal Specifications P-D-680. Surfaces not requiring the use of mechanical abrasives or chemical paint removers shall be cleaned with a dry cleaning solvent to remove grease, oil, corrosion preventives, dust, dirt, and moisture prior to bonding.

5) Clad Metals. Clad metals shall be cleaned with fine steel wool or grit in such a manner that the cladding material is not penetrated by the cleaning process. A bright, smooth surface shall be achieved. The cleaned area shall be wiped with dry cleaning solvent and allowed to air dry before completing the bond.

6) Aluminum Alloy. After cleaning of aluminum surfaces to a bright finish, a brush coating of iridite or other similar conductive finishes shall be applied to the mating surfaces.

7) Completion of the Bond. If an intentional protective coating is removed from the metal surface, the mating surfaces shall be joined within 30 minutes after cleaning.

F.1.19 Dissimilar Metals

All mating surface materials that comprise a bond shall be identified. Compression bonding with the use of bolts or clamps shall be utilized only between metals having acceptable coupling values as indicated in DCA Notice 310-70-1. When the base metals form couples that are not allowed, the metals shall be plated, coated, or otherwise protected with a conductive finish, or a material compatible with each shall be inserted between the two base metals. It shall be constructed from or plated with an appropriate intermediate metal.

[redacted]

F.1.20 Corrosion Prevention (Below Grade)

Because of galvanic corrosion between dissimilar metals, below grade and/or high moisture areas, the welded or brazed joint shall be covered with pitch or other suitable waterproof compound to inhibit corrosion.

F.2 ASSEMBLY

The following subparagraphs deal with special installations peculiar to hardness concept designs.

F.2.1 Rigid Conduit, Threaded Connections

Rigid conduit (new or old installations) used for shielding or rf returns shall be assembled as follows:

1) Cleaning. All mating surfaces for threaded connections shall be prepared as in paragraph F.1.18.
2) Assembly. Apply cold galvanizing compound* "Galvicon" to thread parts and assemble wet. Wipe off excess and let joint dry.
3) Corrosion Protection. Protect the connection as in paragraph F.1.3.

F.2.2 Rigid Conduit, Box or Cabinet Connection

Rigid conduit (new or old installations) used for shielding or rf returns shall be assembled as follows:

1) Cleaning. All faying surfaces shall be prepared as in paragraph F.1.18.

* Kenco Divison
Southern Coatings and Chemical Co., Inc.
Sumter, South Carolina 29150

2) Assembly. Assemble using a rigid conduit metallic bushing and bonding type lock nut.

3) Corrosion Protection. Protect the connection as in paragraph F.1.3.

F.2.3 Coaxial Cable, Severe Environment

Coaxial cable connections exposed to outdoor environments or high humidity shall be assembled as follows:

1) Cleaning. All metal surfaces shall be prepared as in paragraph F.1.18.

2) Assembly. Assemble connectors and clean as in paragraph F.1.18.

3) Corrosion Protection. Apply Dow Corning** 3145 RTV adhesive/ sealant (non-corrosive) on the connector forming a seal to preclude migration of water or vapor down the cable or at the threaded portion of the connector.

F.2.4 Coaxial and Shielded Cable, Intermediate Point Bonding

Cables requiring attachment of ground straps at points other than cable ends shall be prepared as follows:

1) Cleaning. Remove at least 3 cable diameters of the protective sheath to expose the cable shield. Prepare the shield surfaces as in paragraph F.1.18 except that any solvents used for cleaning shall be compatible with the cable dielectric and the insulating material.

** Dow Corning Corporation
Midland, Michigan 48640

2) Assembly. Shield bonding is achieved by using a cable clamp to which a flat bonding strap is attached. To avoid crushing the cable dielectric and insulating material, fabricate a pressure sleeve which will be installed under the bonding clamp to distribute clamping pressure over a larger area. The pressure sleeve should be flared on each end, split to facilitate assembly and have a length of about 2 cable diameters. Thin wall copper tubing slightly smaller than the cable diameter should be used and tinned both inside and out with a 50/50 solder using a non-corrosive flux. Install the sleeve and an AN735 type bonding clamp. Prepare a bonding strap of tinned copper flat braid of the largest size possible that is compatible with the terminal lug size determined by the required pressure clamp size. The bonding strap should not be more than 6 inches long and shorter if possible. Crimp and solder a lug to each end of the flat braid. Clean the metal parts as in paragraph 1) above and assemble the sleeve, clamp and bonding strap terminal to the cable. Tighten the clamp, but not so tight as to crush the dielectric or wire insulation. Fasten the other end of the bond strap to the ground plane in accordance to the bonding instructions in paragraph F.1.

3) Corrosion Protection. Apply Dow Corning** 3145 RTV adhesive/sealant (non-corrosive) to the cable, sleeve and bonding clamp. Completely cover the bond assembly, overlapping the protective sheath on the cable and the terminal lug on the clamp. Thus, forming a seal to preclude migration of water or vapor down the cable.

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